

SINGLE SHIP ROUTING

by

Willard Evan Bleick

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## SINGLE SHIP ROUTING

*Willard E. Bleick*  
W. E. Bleick

F. D. Faulkner

G. J. Haltiner

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ABSTRACT:

This report presents an operational computer program for the minimal-time routing of single ships. Although written specifically for VC2AP3 and VC2AP2 vessels operating in a described area of the north Pacific ocean, the program can be modified easily to provide routes for other type vessels in any ocean area of the northern hemisphere. The method of incorporating weather forecasts into the preparation of minimal-time ship routes is described, and possible future developments are discussed.

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Prepared by:

W. E. Bleick  
F. D. Faulkner  
Dept. of Mathematics  
G. J. Haltiner  
Dept. of Meteorology & Oceanography

Released by:

C. E. Menneken  
Dean of  
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## I. Introduction.

Section II, by Prof. G. J. Haltiner, describes the scheme of incorporating weather forecasts into the preparation of minimal time ship routes used in this report, and discusses possible future developments. The remaining Sections of the report extend the previous work of Profs. W. E. Bleick and F. D. Faulkner, [1] and [2], by describing an operational computer program for the minimal-time routing of VC2AP3 vessels in a specific area of the north Pacific ocean. A subroutine for AP2 vessels is provided which can be substituted for the AP3 subroutine in the program. The program can be adapted to routes in other ocean areas of the northern hemisphere by changing the Fortran statements on a very small number of cards listed in the Appendix. Some suggestions are made for improving the program.

## II. Use of Long-Range Weather Forecasts in Ship-Routing.

1. The scheme of incorporating weather forecasts into the preparation of the minimal-time ship routes of this report consists of the following parts:

- a) The Fleet Numerical Weather Facility prepares operational wave predictions for periods up to 48 hours. These predictions for 12Z and 24Z of 26 and 27 July 1966 were used for the first two days in the ship voyage example of this report.
- b) The Weather Bureau's 5-day surface pressure forecast was used for the next three days. This forecast, which is prepared every Monday, Wednesday and Friday, consists of one sea-level pressure map per day at 1230Z. Lieutenant D. M. Truax USN [3] used these maps, in a Master of Science thesis project supervised by Prof. Haltiner, to determine the surface winds and, in turn, to calculate the height, period and direction of the wind waves and swell. This calculated data was used at 12Z on July 28, 29 and 30 of the ship voyage example of this report.
- c) The Weather Bureau 30-day forecast was utilized for the remainder of the ship's voyage. Although not published for use outside the Weather Bureau, a copy of the 30-day predicted

mean sea-level pressure map, centered at the middle of the month, was mailed to Prof. Haltiner for the ship routing experiment. Lieutenant Truax [3] estimated surface winds from this single map, and again the wave conditions were calculated. These calculations were repeated on a daily basis using the same map for the remainder of the total forecast period. Since the same winds are used repeatedly during the latter part of the period, the forecast waves reach a steady state within a few days. This steady state forecast was used at 12Z of July 31 and all subsequent days of the ship voyage example of this report.

2. The predicted 30-day mean pressure chart has relatively weak pressure gradients, as would be expected from the averaging process. In contrast, the individual daily charts which make up such a mean have strong gradients in general, particularly in the vicinity of the migratory cyclones or low pressure areas. These systems have strong winds and high seas associated with them, which are reflected in the 30-day mean only in a very limited fashion. The forecast procedure outlined in paragraph 1 did, however, show considerable skill over the use of long term monthly mean charts. Nevertheless it is desirable to seek additional ways, possibly more accurate, of providing wave estimates for the latter part of a voyage extending beyond a 5-day period. One possibility, which appears to have promise, is to develop a wave climatology. This could consist of utilizing the wave analyses now being prepared daily at FNWF to compute mean wave height, direction and period as a function of latitude and longitude for each month of the year. These data could then be compared with those derived from the Weather Bureau 30-day sea level pressure forecasts in order to ascertain the best source of wave data for trans-oceanic ship routing. Such a wave climatology would have other applications in Naval operations as well. A further refinement in the development of a suitable wave climatology for use in ship routing might consist of the preparation of mean wave char-

acteristics not only as a function of latitude, longitude and month, but also separated according to weather type. The latter are determined largely according to the main storm tracks which vary from week to week as well as with seasons. Such a climatology would obviously take more effort to prepare, but would be a very valuable aid in ship routing.

3. Finally, it should be mentioned that a number of groups are experimenting with long-range weather prediction by numerical integration of the hydrodynamical equations. It is expected that eventually such predictions will show skill for perhaps several weeks, and thus day-by-day wave forecasts could be made available for the entire period of a trans-oceanic voyage.

### III. Input and Output of the Computer Program.

1. The program VC2AP3, page 20 of the Appendix, was written for the Control Data Corporation 1604 computer in Fortran 1963, which is their version of the IBM Fortran IV. The  $63 \times 63$  grid of the northern hemisphere stereographic projection of the Fleet Numerical Weather Facility was used to specify the location of the ocean wave data as explained in [1] and [2]. It was desired that the 32764-word memory of the CDC 1604 contain wave data for as large a part of the  $63 \times 63$  grid as possible in order to take advantage of high-speed random access to core memory. This was accomplished by packing the floating-point wave height  $H$  and wave direction  $K$  at a grid point into a single computer word, with height in the upper half and direction in the lower half word. Program TAPE, page 33 of the Appendix, describes how the fixed-point FNWF wave field data was transformed to packed floating-point form. The conversion of the right-shifted FNWF fixed-point data to floating-point was accomplished by hardware features peculiar to CDC computers, and probably not existing in IBM computers, involving normalization by addition to fixed-point octal 2000000000000000 followed by addition to floating-point zero. The packing and subsequent unpacking was accomplished by CDC Fortran 1963 operations. The right or left shifts involved were simulated by division or multiplication by the integer 16777216

decimal. The packing and unpacking also used a CDC Fortran 1963 masking operation which does not exist in IBM Fortran IV.

2. The grid wave data magnetic tape output of program TAPE is read as input from Logical Tape Unit 1 by the main program VC2AP3. It is stored in core memory as the three-dimensional MHD array of DIMENSION (18,32,8) with a total of 4608 words. The dimensions 18 and 32 correspond to FNWF stereographic projection plane grid point indices of  $8 \leq i \leq 25$  in the direction of the 10E longitude meridian and  $16 \leq j \leq 47$  in the direction of the 100E longitude meridian. The dimension of 8 corresponds to the time series of predicted wave fields as described in Section II, page 3, for 12Z and 24Z of 26 and 27 July, 12Z on July 28, 29 and 30, and the final steady-state forecast used at 12Z of July 31 and all subsequent days. The 18 by 32 rectangular field of data is shown on the map of Figure 1, page 8. The ship routing program will not work unless all points of the ship route, including the initial and terminal points, are within a smaller 16 by 30 rectangle also shown in Figure 1, defined by  $9 \leq i \leq 24$  and  $17 \leq j \leq 46$ . A local coordinate system for the rectangular array is set up in the VC2AP3 program with the origin 0 at  $i=7$  and  $j=15$ , with the  $Ox$  and  $Oy$  axes in the direction of increasing  $i$  and  $j$  respectively. The smallest values of  $x$  and  $y$ , corresponding to  $i=8$  and  $j=16$ , are therefore  $x=1$  and  $y=1$ .

3. The MHD array of wave data in core memory may be extended from the present 4608 words to a maximum of 21156 words to accommodate a larger ocean area or a longer time series, or both. This is accomplished by the relocation of COMMON feature of Fortran 1963 by using the following cards after the MCS control card:

-BINARY,56. (The dash in column 1 is a 7 and 9)  
-RELOCOM. (The dash in column 1 is a zero, 7, 9 and minus)  
-FTN,L,A,E. (The dash in column 1 is a 7 and 9)

and replacing the -EXECUTE. card by -EXECUTER. A change in the present geometric dimensions and/or origin of the MHD array must be accompanied by rather obvious changes in certain cards of programs TAPE and VC2AP3. A list of the cards requiring a change is

given on page 36 of the Appendix. A change in the time dimension of the MHD array, corresponding to an increase in the length of the time series, must be accompanied by rather obvious changes in cards 382, 394 and 399 of subroutine TERP, with card 404 being changed to IF (L-5) 14,5,5. An increase in the time dimension requires changes in cards 13 and 85 of program TAPE, and in the format statements of cards 18, 21, 52, 55, 64 and 67.

4. The first two of the BCD punched card input to the program VC2AP3, following the -EXECUTE. card, contain the data:

Card 1: First line of the TI=IT title in format (6A8/) for the map produced by subroutine DRAW in Statement 11. See example on page 32 of the Appendix, and explanation of the DRAW subroutine on page 37 of the Appendix.

Card 2: Format (8A8,I3) of which 6A8 is the second line of the map title TI. The remaining part of the format is A8 for the DATE=KATE of the routing computation, A8 for eight blank Hollerith characters for a null label AL=LA on the map grid plot, and I3 for the NST total number of ships to be routed by the program. The DATE of the routing computation corresponds to the 12Z hour of the first member of the time series in the MHD array. See example on page 32 of the Appendix.

Following these two BCD cards there are groups of either 6 cards or one card for each ship routed by the program, depending on whether or not the option to plot an earlier route of a particular ship is elected.

Card 3: Format (A4,2A8,F3.0,F6.1,F5.1,F6.1,F5.1,F3.0,I1,2I2,I1, F8.5,F6.3) with example on page 32 of the Appendix. The first A4 is the GL=LG ship identification number with column 1 of the card blank, used by the DRAW subroutine to label the terminal point of a ship route. The first A8 is the DATEX=KATEX date on which the ship leaves the initial point of its route. The second A8 is the FL=LF Julian date of departure, with blanks in columns 17 to 20 inclusive, used by the DRAW subroutine to label the initial point of a ship route. The F3.0 is the HR hour of ship departure from its initial point measured from 12Z on the DATE of routing, i.e. from the 12Z hour of the first member of the time series in the MHD array. The F6.1, F5.1, F6.1, F5.1 formats are the longitudes and latitudes of the initial and terminal points of the route, XLG1, XLT1, XLG2, XLT2, with the longitudes considered positive if east of the Greenwich meridian. The F3.0 format provides for the RMUL convergence factor discussed later on pages 11 and 16. Note the absence of a decimal point in the example on page 32. The I1 for-

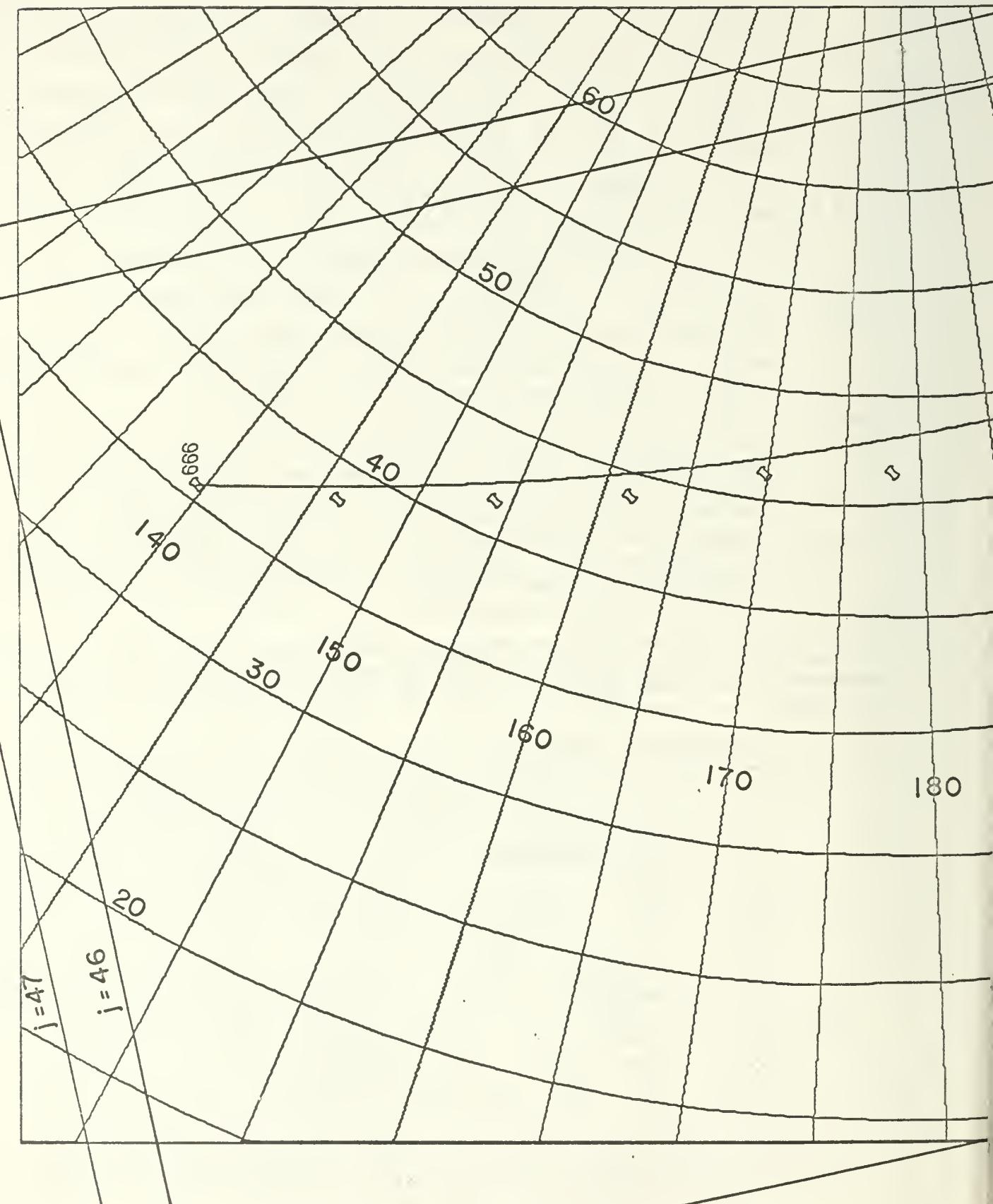


FIG. 1. (Left side). J207 day route of ship 666.

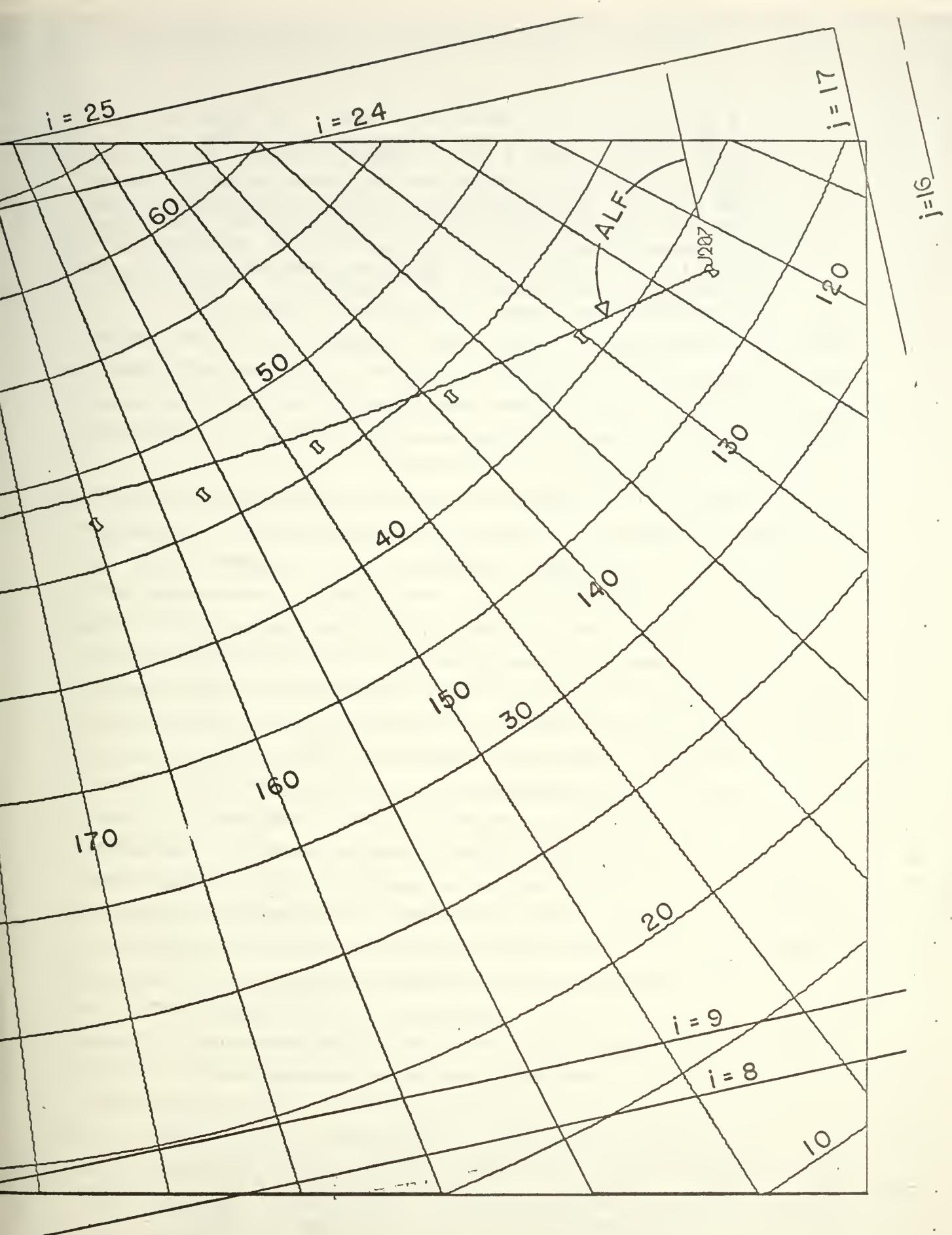


FIG. 1. (Right side). J207 day route of ship 666.

mat provides for NN which is either 1 or zero according as the option to plot an earlier route of the ship is or is not elected. The first of the 2I2 format is for the NSTEP reciprocal of the time step used in the integration process, with 24 of the example indicating a time step of 1/24 of a day. The second I2 format specifies the number LMAX of iterations allowed in determining the minimal-time route. The remaining formats I1, F8.5, F6.3 provide for the variables NP, PALF and PT used in an option described later in Section IV, page 13.

Card 3 is followed by five BCD cards punched out by the statements on cards 334 to 338 of an earlier use of program VC2AP3 if the option NN=1 to plot an earlier track of the ship has been elected. If NN=0 on card 3, the remaining BCD cards of the input deck refer to other ships to be routed.

5. The output of the program is a map grid for each vessel routed, shown in Figure 1, produced by the CALL DRAW of statement 11. The details of subroutine DRAW are given on page 37 of the Appendix. If the option NN=1 has been elected, statements 16 to 18 cause an earlier route of the ship to be plotted as in Figure 2, using plus signs for daily positions and an identifying Julian day mark for the initial point. Statements 19 to 44 cause a geodesic route for the ship to be computed and plotted as a solid line. Figures 1 and 2 give examples of this with the ship's angle of departure ALF, measured counterclockwise from the Ox axis, also indicated. The terminal point of the geodesic route plot is marked by the GL=LG identification number of the ship. The purpose of the geodesic route computation is to find first approximations to the time T and angle of departure ALF used in the LMAX iterations toward a minimal-time route of statements 45 to 69. The computation of the route is abandoned if any point of the geodesic route falls outside of the rectangle  $9 < i < 24$  and  $17 < j < 46$ , but the geodesic route within this rectangle is plotted on the map grid. The minimal-time route computation is initiated by statement 45 only if the entire geodesic route has been computed successfully. The format of statement 71 is printed if the LMAX iterations result in a ship route terminal point more than 100 nautical miles from the desired destination, together with

advice about how to improve the convergence of the iterative process. Experience to date on trans-Pacific routes indicates that it is desireable to use LMAX=7 and a convergence factor, discussed in this paragraph and later in Section IV, RMUL=10. The statement of card 313 gives the DIFA change in ALF for the next of the LMAX iterations as computed from the Newton-Raphson equations (6) on page 19. This value of DIFA may be grossly in error if non-linearities in the ocean wave field happen to be more important than the linear terms on which the Newton-Raphson equations are based. The statement of card 315 attempts to control the bad effects of such large non-linearities by dividing DIFA by a convergence factor RMUL before accepting it for the next iteration. If RMUL is chosen too large the convergence may be rapid, but the search made for a minimal-time route may be over such a small area of the ocean that the minimum obtained is local rather than global. The choice of too large a value of RMUL may actually lead in some cases to a local extremal with time greater than the geodesic route time. On the other hand too small a value for RMUL may lead to divergent oscillations. Another convergence difficulty, associated with the value of ALF generated by the geodesic track computation, is discussed in Section IV, page 13. Revisions of the program to overcome these convergence difficulties are suggested in Section V, page 16. Some monitoring of the program output will be required until the suggested program revisions have been accomplished.

6. The tabulated daily ship position, wave height and direction for the last of the LMAX iterations are printed under the format of statements 73 and 74. An example of this output is given on page 12, corresponding to the input IBM card on the bottom of page 32. Corresponding to this example the following five IBM cards are punched

666	J207	13									
15.4014.3513.4312.6511.9111.4511.0810.6810.6710.35	666	J207	1								
10.3010.3210.53	0	0	0	0	0	0	666	J207	2		
3.05 5.06 7.09 9.1610.9312.5914.3016.1418.0019.93	J207	666	1								
21.8724.1326.14	0	0	0	0	0	0	J207	666	2		

under the formats of statements 76 and 78, which may be used for

PRINT output for J207 day route of ship 666.

TOTAL NUMBER OF VC2AP3 SHIPS ROUTED = 1  
ON JUL26,66 FROM 12Z TO 24Z, AND ON FOLLOWING DAY FROM 00Z TO 11Z

ROUTE OF SHIP 666 BEGINS ON JUL26,66, JULIAN DATE = J207,  
0 HOURS AFTER 1200Z ON JUL26,66  
FROM LONGITUDE = -122.5 AND LATITUDE = 37.9  
TO LONGITUDE = 139.6 AND LATITUDE = 35.6

RNUL= 10 LMAX= 7 NSTEP=24 NN=0 NP=0

L	N1	ALF	T	X(N1)	XFIN	Y(N1)	YFIN
0	288	1.81954	11.949	13.778	13.778	28.357	28.357
1	288	1.81954	11.949	14.613	13.778	28.159	28.357
		1.82360	11.944				
2	288	1.82360	11.944	14.254	13.778	28.212	28.357
		1.82600	11.953				
3	288	1.82600	11.953	14.054	13.778	28.311	28.357
		1.82731	11.930				
4	288	1.82731	11.930	13.782	13.778	28.368	28.357
		1.82731	11.924				
5	288	1.82731	11.924	13.778	13.778	28.357	28.357
		1.82731	11.924				
6	288	1.82731	11.924	13.778	13.778	28.357	28.357
		1.82731	11.924				
7	288	1.82731	11.924	13.778	13.778	28.357	28.357
		1.82731	11.924				

DAYS OF TRAVEL	LONGI- TUDE	LATI- TUDE	WAVE HEIGHT	WAVE DIRECTION FROM NORTH
0	-122.5	37.9	6	354
1.00	-130.3	41.1	5	11
2.00	-138.9	43.8	2	191
3.00	-148.2	46.0	5	156
4.00	-156.9	46.7	21	177
5.00	-164.9	47.3	21	165
6.00	-173.1	47.3	21	164
7.00	178.2	46.5	18	122
8.00	169.7	46.1	19	146
9.00	161.6	43.8	13	124
10.00	154.0	41.6	17	357
11.00	146.1	38.5	10	116
11.92	139.6	35.6	-1	2

GRAPH TITLED  
JOB 0574 BLEICK BOX 6  
VC2AP3 DECEMBER 6 1966  
HAS BEEN PLOTTED.

some later plot of the track if the NN=1 option of card 33 of the program is elected in a later routing of the ship. The card 339 statement causes the daily track positions to be plotted on the map grid by diamond-shaped symbols, as in Figure 1, with the LF=FL Julian day identification of the initial point. Statement 80 continues the M=1, NST loop to proceed with the routing of the next ship.

#### IV. Example of Options NN=1 and NP=1.

An example of the use of the NN=1 option is given in Figure 2 where the Julian J207 day route of ship 666 is plotted with plus signs. The ship had departed considerably from its J207 routing during the first 24 hours and required a new route from longitude -130.0 and latitude 35.0 starting at 12Z on Julian day J208. It was necessary to resort to the simulation of putting HR=24 on this new route since a new time series MHD array starting at 12Z on J208 was not available. Considerable difficulties were encountered in computing a global-extremum J208 day minimal-time route. The angle of departure ALF generated by the geodesic route computation may have bias to the extent that successive track iterations always go around a storm area on the same side, when actually the other side would be a better choice. The geodesic track time was  $T=11.385$  days and angle of departure  $ALF=1.73554$  radians. This ALF was a poor initial approximation to that required for the final successful minimal-time route of Run 3, as indicated by the successive runs of the following table:

Run	NP	Route	Type of mode	Graph Fig. 2	NP=1 input			Converged VC2AP3 output		
					RMUL	LMAX	PALF	PT	ALF	T
0		Geo-desic	Solid line						1.73554	11.385
1	0	Local extreme	Dashed line		10	10			1.749	11.567
2	1	Local extreme	Dashed line		4	6	1.81200	10.967	1.814	11.682
3	1	Global extreme	Diamond symbols	999	7	1.90000	11.250	1.90003	11.264	

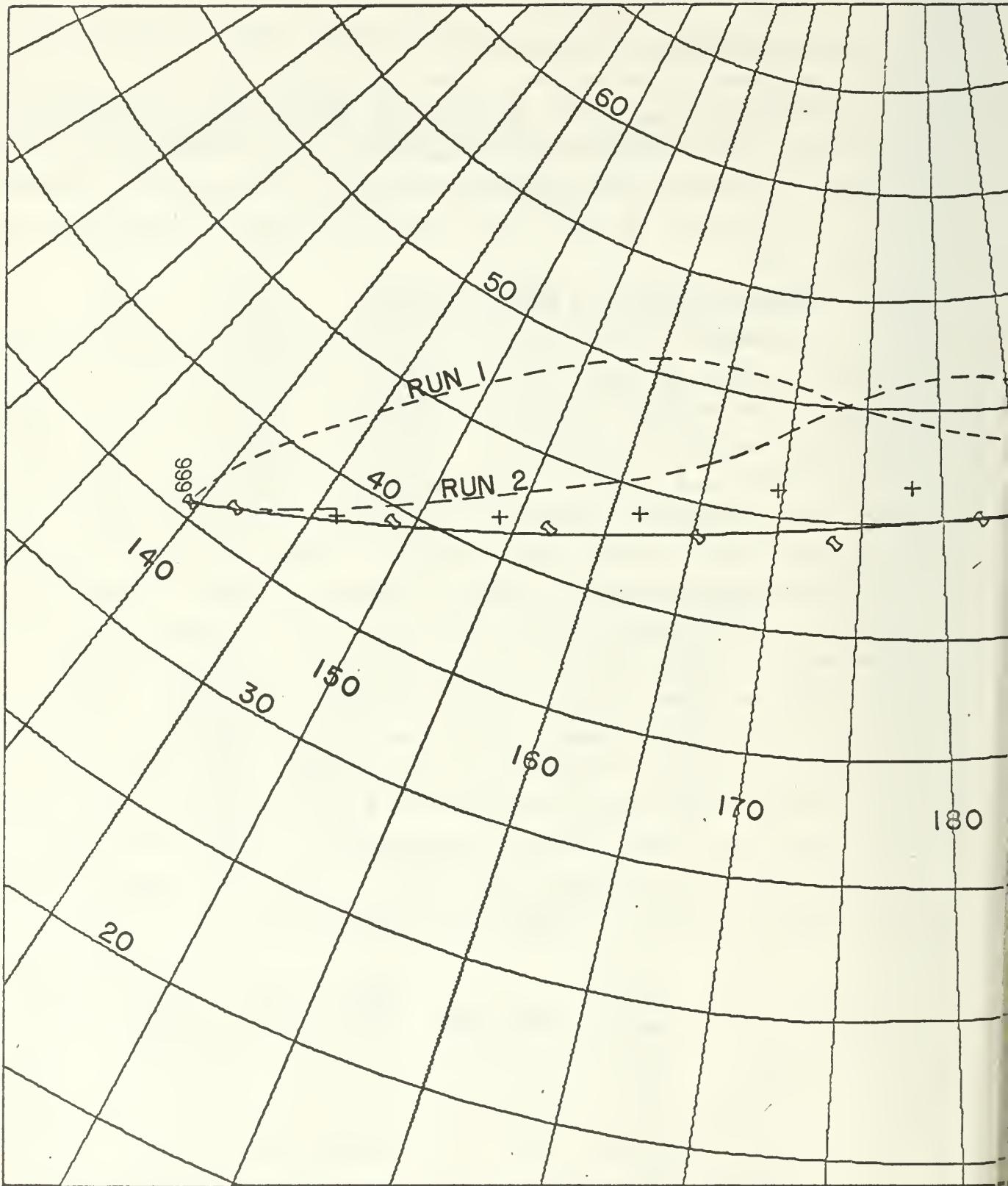


FIG. 2. (Left side). J208 day route with options NN=1 & NP=1

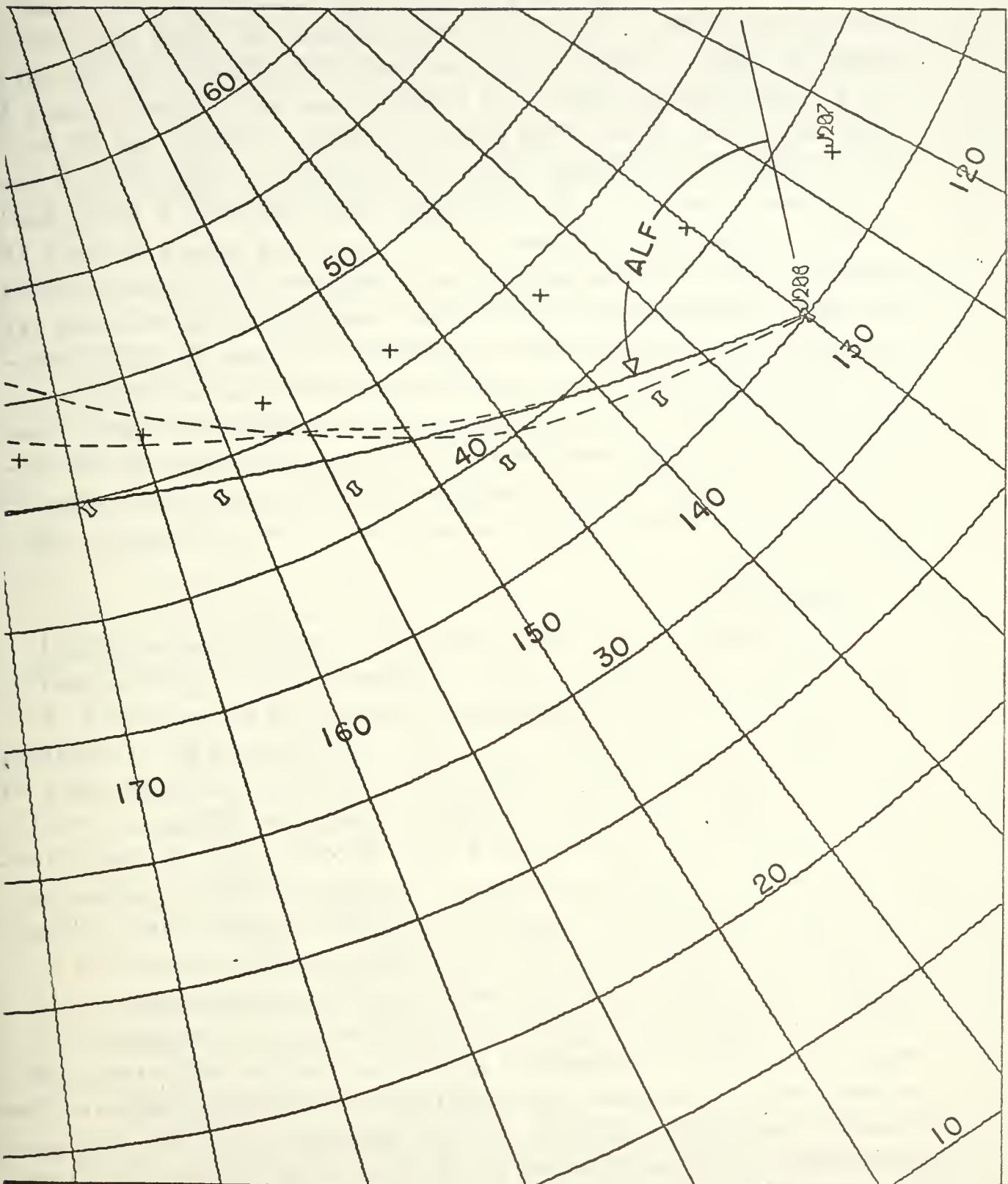


FIG. 2. (Right side). J208 day route with options NN=1 & NP=1

The program VC2AP3 provides the option to override the values of ALF and T generated by the geodesic route computation by using NP=1 in column 54 of the first ship-related IBM input card described on page 7, and to start the LMAX iterations with the values ALF=PALF (format F8.5) and T=PT (format F6.3) from columns 55 to 68 inclusive of this IBM card. The values of PALF and PT in Runs 2 and 3 of the above table were chosen by inspection of the iterations produced in earlier runs. Note that Runs 1 and 2 converged to local time-extremal routes requiring more time than the geodesic route. The successful Run 3 required the input RMUL=999 and PALF=1.90000 radians, the former probably being somewhat larger than really required for convergence. The nearby input RMUL=100 and PALF=1.90000 were tried without obtaining convergence. The extreme value of the convergence factor RMUL=999 used in Run 3 and the resulting sensitivity in the required value of the input angle of departure PALF suggest that the non-linear terms neglected in the Newton-Raphson equations are very strong on the J208 day route.

#### V. Conclusions.

1. It is suggested that any future revision of program VC2AP3 take steps to reduce the computer running time of a trans-Pacific track iteration from the present 1 minute and 47 seconds to an attainable 13 seconds. This is accomplished easily by eliminating the calculation of 128 sine and cosine functions on each entry of subroutine TERP. Under this proposed scheme the MHD array would store a grid-point wave height H only in each word. Two additional 4608-word arrays would store the CK and SK trigonometric functions, computed once only in a modified program TAPE. Assuming that the time dimension of these three arrays remains at 8, the CDC 1604 memory capacity would even allow the geometric dimensions to be chosen to cover 881 grid points, an increase of about 53% from the present 576 grid points of the MHD array. This proposal would eliminate the normalizing and masking hardware features of the program peculiar to CDC computers, and make the program useable in other Fortran IV systems. Even larger dimensions

for the three arrays could be achieved by using a more realistic graph plotting program to replace subroutine DRAW with its exorbitant demand for 5760 words of core memory. Care would have to be exercised in implementing this proposal since the X(900) and Y(900) arrays of subroutine DRAW are used by program VC2AP3 for other memory-conserving purposes.

2. It is suggested that any future revision of program VC2AP3 try to go beyond the present linear Newton-Raphson scheme, and attempt to include quadratic terms also. Such a change might overcome the convergence difficulties disclosed in Section IV. If such a quadratic scheme were found and used successfully, it may be possible to obtain a considerable reduction in the LMAX number of track iterations required to achieve convergence.

3. In order to reduce the amount of monitoring of output required in program VC2AP3, it is suggested that any future revision of the program attempt to include as far as possible the following recommendations of Schmieg, [5] pages 30, 31 and 37:

- a) Check the Legendre and Weierstrass<sup>conditions</sup> for a minimal-time route at each time step of the numerical integration. This check may give an automatic method of eliminating local time-extremal routes which are not the desired global minimal-time route.
- b) Examine the magnitude of the Hamiltonian at the end of each of the LMAX iterations to determine whether it has diminished from its value at the end of the previous iteration. If not diminished choose an appropriate convergence factor RMUL to get ALF for the next track iteration.

## VI. Acknowledgements.

The authors are indebted to LT Daniel Mack Truax USN, whose Master of Science degree thesis [3] provided the predicted ocean wave fields at 12Z on July 28, 29, 30 and 31 as described in Section II, and to CDR Leo C. Clarke USN Ret. of the FNWF, who

assembled all of the ocean wave field data described in Section II on a single magnetic tape used as part of the input to the Fortran 1963 program TAPE of this report.

### VII. Mathematical Theory.

1. A misprint in equation (16) of [1] and [2] requires correction by replacing  $R$  by  $R^2$ . The  $\delta p$  of this equation is an approximation in that certain terms obtained in the differentiation of equation (10) have been dropped as being unimportant. While the approximation is useful for a short ship route, it is desireable to use the following completely accurate expression for a long trans-Pacific route

$$\delta p = \frac{1}{D} [R^2 |E| \Lambda^{-2} \delta \alpha + (V_{px} V - V_p V_x) \delta x + (V_{py} V - V_p V_y) \delta y], \quad (1)$$

where  $D = V_p^2 + 2V_p^2 - VV_{pp}$ . Use of this new expression for  $\delta p$  with equations (14), (16) and (18) of [1] and [2] gives the following pair of inhomogeneous differential equations as a replacement for equation (19) of these references

$$\frac{d}{dt} (\lambda_1 \delta x + \mu_1 \delta y) = \frac{R}{\Lambda D} [\lambda (VV_{py} - V_p V_y) - \mu (VV_{px} - V_p V_x)] (\lambda_1 \delta x + \mu_1 \delta y) - \sin \alpha \frac{|E|}{D} \left( \frac{R}{\Lambda} \right)^3 \delta \alpha \quad (2)$$

$$\frac{d}{dt} (\lambda_2 \delta x + \mu_2 \delta y) = \frac{R}{\Lambda D} [\lambda (VV_{py} - V_p V_y) - \mu (VV_{px} - V_p V_x)] (\lambda_2 \delta x + \mu_2 \delta y) + \cos \alpha \frac{|E|}{D} \left( \frac{R}{\Lambda} \right)^3 \delta \alpha.$$

Let  $y_7$  be a solution of either of (2), rendered homogeneous by putting  $\delta \alpha = 0$ , and with  $y_7(0) = 1$ . Then a solution of (2) with  $\delta \alpha \neq 0$ , and with vanishing initial values is

$$\begin{aligned} (\lambda_1 \delta x + \mu_1 \delta y)_T &= -y_7(T) y_8(T) \sin \alpha \delta \alpha \\ (\lambda_2 \delta x + \mu_2 \delta y)_T &= +y_7(T) y_8(T) \cos \alpha \delta \alpha \end{aligned} \quad (3)$$

where

$$y_8(T) = \int_0^T \frac{|E|^2}{y_7(t) D} (R/\Lambda)^3 dt. \quad (4)$$

The solution of (3) gives the following new version of equations (19) of [1] and [2]

$$[\delta x, \delta y]_T = y_7(T)y_8(T)\delta\alpha[-\mu, \lambda]_T / |\underline{E}(T)|, \quad (5)$$

and the Newton-Raphson equations (22) of these references are replaced by

$$\begin{aligned} \dot{x}(T)\Delta T - [\mu y_7 y_8 / |\underline{E}|]_T \delta\alpha &= \Delta x(T) \\ \dot{y}(T)\Delta T + [\lambda y_7 y_8 / |\underline{E}|]_T \delta\alpha &= \Delta y(T). \end{aligned} \quad (6)$$

2. The subroutines AP3 and AP2 of the Appendix are based on the work of James [4]. His speed versus wave height data for these vessels have been approximated by arcs of hyperbolas as explained in [1] and [2].

#### VIII. References.

1. W. E. Bleick and F. D. Faulkner, Minimal-Time Ship Routing (includes Fortran programs), Research Paper No. 46, 18 pages, August 1964. Replace R by  $R^2$  in Eq.(16) to correct misprint.
2. W. E. Bleick and F. D. Faulkner, Minimal-Time Ship Routing, Journ. of Applied Meteor., 4, 217-221 (1965). Replace R by  $R^2$  in Eq.(16) to correct misprint.
3. D. M. Truax, Use of Extended Range Forecasts in Ship Routing, thesis submitted in partial fulfillment for degree of Master of Science in Meteorology, Naval Postgraduate School, 25 pages, October 1966.
4. R. W. James, Application of Wave Forecasts to Marine Navigation, Naval Hydrographic Office, 85 pages, June 1959.
5. G. D. Schmieg, Optimum Submarine Routing II, thesis submitted in partial fulfillment for a degree of Master of Science in Mathematics, Naval Postgraduate School, 72 pages, August 1966.

## IX. Appendix.

-COOP, BOX 6, BLEICK, I/1/0/49/S/56/57/E/45=54,21,10000,0, VC2AP3 - 6 DEC 66.  
-FTN,L,A,E.

PROGRAM VC2AP3

```

C  YVARS(1)=LAMBDA1  YVARS(2)=MU1  YVARS(3)=LAMBDA2  YVARS(4)=MU2      0
C  YVARS(5)=X          YVARS(6)=Y      YVARS(7)=S OR Y7  YVARS(8)=Y8
    DIMENSION MHD(18,32,8),X(900),Y(900),RX(10,90),RY(10,90),          1
    +          IT(12),TI(12),C(4),YVARS(8),YC(8),AK(4,8),DY(8)          2
    COMMON MHD,TC,YC,H,HX,HY,CK,CKX,CKY,SK,SKX,SKY,XK,YVARS,XLG,XLT,          3
    +          A,B,CC,DA,DB,DC,LR          4
    EQUIVALENCE (IT,TI),(LA,AL),(KATE,DATE),(LP,PL),(LG,GL),(LF,FL),          5
    +          (X,RX),(Y,RY),(KATEX,DATEX)          6
    REWIND 1          7
    C(1) = 0.0          8
    C(2) = 0.5          9
    C(3) = 0.5          10
    C(4) = 1.0          11
C  READ MAP GRID DATA FOR DRAW SUBROUTINE, AND WAVE FIELD MATRIX          12
    READ(1) X,Y          12
    READ(1) MHD          12.
C  READ MAP TITLE, DATE OF ROUTING COMPUTATION, MAP GRID PLOT LABEL,          13
C  AND TOTAL NUMBER OF SHIPS ROUTED          14
    READ(50,1) TI,DATE,AL,NST          15
    1 FORMAT (6A8/8A8,I3)          14
    WRITE(51,2) NST,KATE          15
    2 FORMAT (39H1TOTAL NUMBER OF VC2AP3 SHIPS ROUTED = I3/1X3HON A8,54H          16
    +FROM 12Z TO 24Z, AND ON FOLLOWING DAY FROM 00Z TO 11Z/)          17
    REWIND 1          18
    DO 80 M=1,NST          19
    IF (M-1) 10,11,10          20
C  READ MAP GRID DATA FOR DRAW SUBROUTINE          21
    10 READ(1) X,Y          21
    REWIND 1          22
C  DRAW MAP GRID          23
    11 CALL DRAW (386,X,Y,1,0,LA,IT,2.,2.,0,0,2,2,9,15,0,LAST)
C  READ SHIP IDENTIFICATION NUMBER, DATE AND HOUR OF DEPARTURE, COORDINATES          23
C  OF TRACK END POINTS, CONVERGENCE FACTOR, OPTION TO PLOT EARLIER          24
C  TRACK, TIME STEP RECIPROCAL, AND NUMBER OF ITERATIONS          24.
    READ(50,14) GL,DATEX,FL,HR,XLG1,XLT1,XLG2,XLT2,RMUL,NN,NSTEP,LMAX,          24
    + NP,PALF,PT          24.
    14 FORMAT (A4,2A8,F3.0,F6.1,F5.1,F6.1,F5.1,F3.0,I1,2I2,I1,F8.5,F6.3)          25
    RSTEP = NSTEP          25
    WRITE(51,15) LG,KATEX,LF,HR,KATE,XLG1,XLT1,XLG2,XLT2,RMUL,LMAX,          27
    + NSTEP,NN,NP          28
    15 FORMAT(15HORROUTE OF SHIP A4,11H BEGINS ON A8,16H, JULIAN DATE = A429          29
    +,1H,/1XF3.0,22H HOURS AFTER 1200Z ON A8/19H FROM LONGITUDE = F6.130          30
    +,16H AND LATITUDE = F6.1/19H TO LONGITUDE = F6.1,16H AND LATITU31          31
    +DE = F6.1//6H RMUL=F5.0,3X5HLMAX=I2,3X6HNSTEP=I2,3X3HNN=I1,3X3HNP=32          32
    +I1//)
```

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C  CHECK ON OPTION TO PLOT EARLIER TRACK          33
  IF (NN)  16,19,16
16 READ(50,17) GL,PL,NK                         34
17 FORMAT (2A8,I2)
  READ(50,29) (X(I),I=1,20), (Y(I),I=1,20)      35
29 FORMAT (10F5.2)
  CALL DRAW (NK,X,Y,2,2,LP,IT,2.,2.,0,0,2,2,9,15,0, LAST) 36
  WRITE(51,18) LG,LP                            37
18 FORMAT(23H0EARLIER ROUTE OF SHIP A8,15H ON JULIAN DAY A4/66H HAS 40
  +BEEN PLOTTED USING PLUS SIGNS FOR SUCCESSIVE DAILY POSITIONS/) 41
C  COMPUTATION OF GEODESIC TRACK
19 ARG = (XLG1-10.)/57.29577951                  42
  COSLG1= COSF(ARG)                            43
  SINLG1= SINF(ARG)                            44
  ARG = (XLG2-10.)/57.29577951                  45
  COSLG2= COSF(ARG)                            46
  SINLG2= SINF(ARG)                            47
  ARG = XLT1/57.29577951                      48
  COSLT1= COSF(ARG)                            49
  SINLT1= SINF(ARG)                            50
  ARG = XLT2/57.29577951                      51
  COSLT2= COSF(ARG)                            52
  SINLT2= SINF(ARG)                            53
  EL = SINLT2*COSLT1*SINLG1 - COSLT2*SINLT1*SINLG2 54
  EM = -SINLT2*COSLT1*COSLG1 + COSLT2*SINLT1*COSLG2 55
  EN = (SINLG2*COSLG1-COSLG2*SINLG1)*COSLT1*COSLT2 56
  ROOT = SQRTF(EL*EL + EM*EM + EN*EN)          57
  EL = EL/ROOT                                58
  EM = EM/ROOT                                59
  EN = EN/ROOT                                60
  PR1= 31.205*COSLT1/(1.+SINLT1)              61
  X1 = PR1*COSLG1                            62
  Y1 = PR1*SINLG1                            63
  PR2= 31.205*COSLT2/(1.+SINLT2)              64
  X2 = PR2*COSLG2                            65
  Y2 = PR2*SINLG2                            66
  DELX = X2 - X1                            67
  DELY = Y2 - Y1                            68
  S12 = SQRTF(DELX*DELX + DELY*DELY)          69
  ARC= S12                                    70
  IF (XLG2-XLG1) 20,21,20                      71
20 ARG= ABSF(EN/62.41)                          72
  ARC= ASINF(ARG*S12)/ARG                      73
21 COSA = -EN*Y1/31.205 + EM                  74
  SINA = EN*X1/31.205 - EL                    75
  IF (COSA) 23,22,23                          76
22 ALF = SIGNF(1.5707963268,SINA)            77
  GO TO 27                                    78
23 ALF = ATANF(SINA/COSA)                      79
  IF (COSA) 24,27,27                          80

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24 IF (SINA) 26,25,25 81
25 ALF = ALF + 3.1415926536 82
   GO TO 27 83
26 ALF = ALF - 3.1415926536 84
27 N3 = 0 85
   X(1) = X1 + 24. 86
   Y(1) = Y1 + 16. 87
   XFIN = X2 + 24. 88
   YFIN = Y2 + 16. 89
   LR = 0 90
   STEP = 1.0/RSTEP 91
   TAU = 0.0 92
   S = 0.0 93
   TVAR = HR/24. 94
   YVARS(5) = X(1) 95
   YVARS(6) = Y(1) 96
   YVARS(7) = 0.0 97
   N1 = 1 98
   N2 = 1 99
   DO 40 K=2,900 100
   DO 32 I=1,4 101
   TC = C(I)*STEP + TVAR 102
   DO 31 J=5,7 103
31 YC(J) = C(I)*AK(I-1,J) + YVARS(J) 104
   IF (ABSF(YC(5)- 9.5)- 7.5) 97,38,38 105
97 IF (ABSF(YC(6)-16.5)-14.5) 98,38,38 106
98 CALL TERP 107
   CALL AP3 108
   DELX = YC(5) - 24. 109
   DELY = YC(6) - 16. 110
   COSP = -DELY*EN/31.205 + EM 111
   SINP = DELX*EN/31.205 - EL 112
   COST = COSP*CK + SINP*SK 113
   A2MC2= A*A - CC*CC 114
   SPMK = (SINP*CK-COSP*SK)/B 115
   SINTB= SPMK*SPMK*A2MC2 116
   V = A2MC2/(CC*COST + SQRTF(COST*COST+SINTB)*A) 117
   EMFI = (DELX*DELX + DELY*DELY + 973.75)/1043.638743 118
   CAPV = V*EMFI/8.5660416667 119
   DY(5)= CAPV*COSP 120
   DY(6)= CAPV*SINP 121
   DY(7)= CAPV 122
   DO 32 J=5,7 123
32 AK(I,J) = STEP*DY(J) 124
   DO 33 J=5,7 125
33 YVARS(J) = ( AK(1,J)+2.*AK(2,J)+2.*AK(3,J)+AK(4,J) )/6. + YVARS(J) 126
   TVAR = TVAR + STEP 127
   X(K) = YVARS(5) 128
   Y(K) = YVARS(6) 129
   N1 = K 130

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N2 = K 131
IF (YVARS(7)-ARC) 35,34,34 132
34 RAT = (ARC-S)/(YVARS(7)-S) 133
T = STEP*RAT + TAU 133.1
X(K) = (X(K)-X(K-1))*RAT + X(K-1) 133.2
Y(K) = (Y(K)-Y(K-1))*RAT + Y(K-1) 133.3
N2 = K+1 134
X(N2) = XFIN 135
Y(N2) = YFIN 136
GO TO 41 137
35 S = YVARS(7) 138
TAU= TAU + STEP 139
IF (K-900) 36,38,38 140
36 IF (ABSF(X(K)- 9.5)- 7.5) 37,38,38 141
37 IF (ABSF(Y(K)-16.5)-14.5) 40,38,38 142
38 T = TAU 143
WRITE(51,39) LG 144
39 FORMAT(61HMORE THAN 899 INTEGRATION STEPS OR WAVE DATA FIELD EXCE145
+EDED./21H OTS ROUTING OF SHIP A4,4X39HABANDONED BUT GEODESIC TRACK146
+ IS PLOTTED/) 147
N3 = 1 148
GO TO 41 149
40 CONTINUE 150
41 L = 0 151
WRITE(51,42) 152
42 FORMAT(4X1HL4X2HN16X3HALF7X1HT7X5HX(N1)4X4HXFIN5X5HY(N1)4X4HYFIN/) 153
C PRINT WEIGHTING FACTOR ALPHA AND TIME T OF GEODESIC TRACK
WRITE(51,43) L,N1,ALF,T,X(N1),XFIN,Y(N1),YFIN 154
43 FORMAT (I5,I6,F11.5,5F9.3) 155
C ROTATE AND TRANSLATE AXES TO PLOT GEODESIC TRACK ON MAP GRID
DO 44 I=1,N2 156
TEMP = .97780241408*X(I) - .20952908873*Y(I) + 3.0032502718 157
Y(I) = .20952908873*X(I) + .97780241408*Y(I) - 4.4699538929 158
44 X(I) = TEMP 159
CALL DRAW (N2,X,Y,N3+2,0,LG,IT,2.,2.,0,0,2,2,9,15,0, LAST) 160
IF (N3) 80,45,80 161
C PREPARE FOR LMAX ITERATIONS TOWARD MINIMAL-TIME TRACK
45 TC = HR/24. 162
X(1) = X1 + 24. 163
Y(1) = Y1 + 16. 164
YC(5) = X(1) 165
YC(6) = Y(1) 166
CALL TERP 167
DO 9 I=2,399 168
X(I) = 0.0 169
9 Y(I) = 0.0 170
X(101) = H 171
YVARS(5) = X(1) 172
YVARS(6) = Y(1) 173
CALL ANGLE 174

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Y(101) = XK 175
X(201) = XLG1 176
Y(201) = XLT1 177
LR = 1 178
IF (NP) 81,82,81 178.1
81 ALF = PALF
T = PT 178.2
COSA = COSF(ALF) 178.3
SINA = SINF(ALF) 178.4
178.5
82 DO 69 L=1,LMAX 179
TVAR = HR/24. 180
TAU = 0.0 181
N1 = XINTF(RSTEP * T) 182
XN1 = N1 183
STEP1 = 1.0/RSTEP 184
FSTEP = -XN1/RSTEP + T 185
N1 = N1 + 2 186
DO 46 I=1,8 187
46 YVARS(I) = 0.0 188
YVARS(1) = 1.0 189
YVARS(4) = 1.0 190
YVARS(5) = X(1) 191
YVARS(6) = Y(1) 192
YVARS(7) = 1.0 192.1
NK = 1 193
DO 66 K=2,N1 194
STEP = STEP1 195
IF (K-N1) 48,47,48 196
47 STEP = FSTEP 197
48 DO 52 I=1,4 198
TC = C(I)*STEP + TVAR 199
DO 49 J=1,8 200
49 YC(J) = C(I)*AK(I-1,J) + YVARS(J) 201
IF (ABSF(YC(5)- 9.5)- 7.5) 99,65,65 202
99 IF (ABSF(YC(6)-16.5)-14.5) 100,65,65 203
100 XLAM = YC(1)*COSA + YC(3)*SINA 204
XMU = YC(2)*COSA + YC(4)*SINA 205
CLAM = SQRTF(XLAM*XLAM + XMU*XMU) 206
CALL TERP 207
CALL AP3 208
DKX = CK*SKX - SK*CKX 209
DKY = CK*SKY - SK*CKY 210
ABS = (XLAM*CK + XMU*SK)*A/CLAM 211
ORD = (XMU *CK -XLAM*SK)*B/CLAM 212
HYP = SQRTF(ABS*ABS + ORD*ORD) 213
SINB= ORD/HYP 214
COSB= ABS,HYP 215
VMAJ= A * COSB - CC 216
VMIN= B * SINB 217

```

$V = \text{SQRTF}(VMAJ*VMAJ + VMIN*VMIN)$	218
$\text{COSP} = (CK*VMAJ - SK*VMIN)/V$	219
$\text{SINP} = (SK*VMAJ + CK*VMIN)/V$	220
$\text{COST} = VMAJ/V$	221
$VBR = V/8.5660416667$	222
$\text{DELX} = YC(5) - 24.$	223
$\text{DELY} = YC(6) - 16.$	224
$\text{EMFI} = (\text{DELX}*\text{DELX} + \text{DELY}*\text{DELY} + 973.75)/1043.638743$	225
$\text{CAPV} = VBR * \text{EMFI}$	226
$\text{DY}(5) = \text{CAPV} * \text{COSP}$	227
$\text{DY}(6) = \text{CAPV} * \text{SINP}$	228
$\text{EMFIX} = \text{DELX}/521.8193715$	229
$\text{EMFIY} = \text{DELY}/521.8193715$	230
$\text{B2MA2} = B*B - A*A$	231
$\text{AMCCB} = -CC*COSB + A$	232
$\text{ACPDCB} = A*CC + \text{B2MA2*COSB}$	232.1
$\text{RAT} = (\text{ACPDCB} * \text{SINB}/B) / \text{AMCCB}$	233
$\text{VP} = \text{RAT} * V$	234
$\text{CAPVP} = \text{RAT} * \text{CAPV}$	235
$\text{QUO} = V/\text{AMCCB}$	236
$\text{DIV} = 1.0$	237
$\text{IF} (\text{RAT}) 12,13,12$	238
$\text{DIV} = \text{RAT} * \text{RAT} + (\text{B2MA2} * \text{SINB} * \text{SINB}/B - \text{VP} * \text{COST} / \text{SINB}) * \text{QUO} * \text{QUO} / B + 1.$	239
$\text{DET} = YC(1) * YC(4) - YC(2) * YC(3)$	240
$\text{QUO} = \text{SQRTF}(\text{RAT} * \text{RAT} + 1.0) / \text{CLAM}$	241
$\text{FORCE} = \text{CAPV} * \text{DET} * \text{DET} * \text{QUO} * \text{QUO} * \text{QUO} / \text{DIV}$	242
$\text{FNUM} = -\text{RAT} * \text{AMCCB}$	243
$\text{DBDH} = (\text{DA} * \text{COSB} - \text{DC}) * \text{COSB} + \text{A} * \text{DB} * \text{SINB} * \text{SINB}/B$	244
$\text{RATX} = (\text{FNUM} * \text{DKX} + \text{HX} * \text{DBDH}) / \text{AMCCB}$	245
$\text{RATY} = (\text{FNUM} * \text{DKY} + \text{HY} * \text{DBDH}) / \text{AMCCB}$	246
$\text{CAPVX} = (\text{RATX} * \text{EMFI} + \text{EMFIX}) * \text{VBR}$	247
$\text{CAPVY} = (\text{RATY} * \text{EMFI} + \text{EMFIY}) * \text{VBR}$	248
$\text{F1} = (((((\text{A} + \text{AMCCB}) * \text{B2MA2} * \text{COSB} + \text{A} * \text{A} * \text{CC}) * \text{COSB} - (\text{CC} * \text{CC} + \text{B2MA2}) * \text{A}) / \text{AMCCB}) /$	248.01
$+ \text{AMCCB}) / B$	248.02
$\text{F2} = ((\text{DA} / \text{A} - \text{DB} / \text{B}) * \text{COSB} - \text{DC} / \text{A}) * \text{SINB} * \text{F1}$	248.03
$\text{F3} = (\text{CC} * \text{SINB} * \text{F1} / \text{A}) / \text{CAPV}$	248.04
$\text{F4} = ((\text{ACPDCB} * \text{COSB} - \text{B} * \text{B}) * \text{F1} / \text{A}) / \text{B}$	248.05
$\text{F5} = (((\text{B} * \text{DB} - \text{A} * \text{DA}) * 2.0 * \text{COSB} + \text{CC} * \text{DA} + \text{A} * \text{DC}) / \text{ACPDCB} - \text{DB} / \text{B} + (\text{DC} * \text{COSB} - \text{DA}) /$	248.06
$+ \text{AMCCB}) * \text{RAT}$	248.07
$\text{QUOX} = (\text{F2} + \text{F5}) * \text{HX} + \text{F3} * \text{CAPVX} + \text{F4} * \text{DKX}$	248.08
$\text{QUOY} = (\text{F2} + \text{F5}) * \text{HY} + \text{F3} * \text{CAPVY} + \text{F4} * \text{DKY}$	248.09
$\text{CAPVPX} = \text{CAPVX} * \text{RAT} + \text{CAPV} * \text{QUOX}$	248.10
$\text{CAPVPY} = \text{CAPVY} * \text{RAT} + \text{CAPV} * \text{QUOY}$	248.11
$\text{F6} = (-\text{RAT} * \text{CAPVX} + \text{CAPVPX}) * \text{QUO} / \text{DIV}$	248.12
$\text{F7} = (-\text{RAT} * \text{CAPVY} + \text{CAPVPY}) * \text{QUO} / \text{DIV}$	248.13
$\text{F8} = \text{F7} * \text{XLAM} - \text{F6} * \text{XMU}$	248.14
$\text{DY}(7) = \text{F8} * YC(7)$	248.15
$\text{DY}(8) = \text{FORCE} / YC(7)$	248.16

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SUM = YC(1)*COSP + YC(2)*SINP 249
DY(1) = -CAPVX * SUM 250
DY(2) = -CAPVY * SUM 251
SUM = YC(3)*COSP + YC(4)*SINP 252
DY(3) = -CAPVX * SUM 253
DY(4) = -CAPVY * SUM 254
DO 52 J=1,8 255
52 AK(I,J) = STEP * DY(J) 256
DO 53 J=1,8 257
53 YVARS(J) = ( AK(1,J)+2.*AK(2,J)+2.*AK(3,J)+AK(4,J) )/6. + YVARS(J) 258
  TVAR = TVAR + STEP 259
  TAU = TAU + STEP 260
  IF (N1-K) 54,56,54 261
54 IF (LMAX-L) 62,55,62 262
55 IF ((K-1)/NSTEP+1-NK) 62,62,56 263
56 NK = NK + 1 264
  XLAM = YVARS(1)*COSA + YVARS(3)*SINA 265
  XMU = YVARS(2)*COSA + YVARS(4)*SINA 266
  CLAM = SQRTF(XLAM*XLAM + XMU*XMU) 267
  YC(5) = YVARS(5) 268
  YC(6) = YVARS(6) 269
  LR = 0 270
  CALL TERP 271
  CALL AP3 272
  LR = 1 273
  ABS = (XLAM*CK + XMU*SK)*A/CLAM 274
  ORD = (XMU*CK - XLAM*SK)*B/CLAM 275
  HYP = SQRTF(ABS*ABS + ORD*ORD) 276
  VMAJ = A * ABS/HYP - CC 277
  VMIN = B * ORD/HYP 278
  V = SQRTF(VMAJ*VMAJ + VMIN*VMIN) 279
  COSP = (CK*VMAJ - SK*VMIN)/V 280
  SINP = (SK*VMAJ + CK*VMIN)/V 281
  DET = YVARS(1)*YVARS(4) - YVARS(3)*YVARS(2) 282
  CONA = -XMU*YVARS(7)*YVARS(8)/DET 282
  CONB = XLAM*YVARS(7)*YVARS(8)/DET 282
  IF (LMAX-L) 61,60,61 283
60 X(NK) = YVARS(5) 284
  Y(NK) = YVARS(6) 285
  X(NK+100) = H 286
  X(NK+300) = TAU 287
  CALL ANGLE 288

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Y(NK+100) = XK 289
X(NK+200) = XLG 290
Y(NK+200) = XLT 291
61 IF (N1-K) 62,67,62 292
62 DELX = YVARS(5) - X(1) 293
DELY = YVARS(6) - Y(1) 294
IF (DELX*DELX + DELY*DELY - S12*S12) 63,65,65 295
63 IF (ABSF(YVARS(5)- 9.5)- 7.5) 64,65,65 296
64 IF (ABSF(YVARS(6)-16.5)-14.5) 66,65,65 297
65 N1 = K 298
T = TAU 299
GO TO 56 300
66 CONTINUE 301
PRINT ALPHA, T, X, AND Y AT END OF EACH ITERATION
67 WRITE(51,43) L,N1,ALF,T,YVARS(5),XFIN,YVARS(6),YFIN 302
DELX = YVARS(5) - 24. 303
DELY = YVARS(6) - 16. 304
EMFI = (DELX*DELX + DELY*DELY + 973.75)/1043.638743 305
DIFX = XFIN - YVARS(5) 306
DIFY = YFIN - YVARS(6) 307
CAPV = V * EMFI/8.5660416667 308
XDOT = CAPV * COSP 309
YDOT = CAPV * SINP 310
DETER= XDOT*CONB - YDOT*CONA 311
DIFT = (CONB*DIFX - CONA*DIFY)/DETER 312
DIFA = (XDOT*DIFY - YDOT*DIFX)/DETER 313
T = DIFT + T 314
ALF = DIFA/RMUL + ALF 315
COSA = COSF(ALF) 316
SINA = SINF(ALF) 317
PRINT NEW VALUES OF ALPHA AND T
WRITE(51,50) ALF,T 318
50 FORMAT (11XF11.5,F9.3) 318.1
69 CONTINUE 319
IF (DIFX*DIFX + DIFY*DIFY - EMFI*EMFI*.2366) . 72,72,70 320
70 WRITE(51,71) LG 321
71 FORMAT(20HO OTS ROUTE OF SHIP A4,47H MORE THAN 100 MILES FROM DEST 322
+INATION BUT TRACK/69H IS PLOTTED. INCREASE RMUL OR LMAX, OR BOTH, 323
+ TO IMPROVE CONVERGENCE.) 324
TABULATE FINAL TRACK DAILY POSITION, WAVE HEIGHT AND DIRECTION
72 WRITE(51,73) 325
73 FORMAT (1HO/4X4H DAYS7X5H LONGI4X5H LATI-5X4H WAVE5X14H WAVE DIRECTION/326
+2X9H OF TRAVEL4X5H-TUDE4X4H TUDE5X6H HEIGHT6X10H FROM NORTH/) 327
WRITE(51,74)(X(K+300),X(K+200),Y(K+200),X(K+100),Y(K+100),K=1,NK) 328
74 FORMAT (F9.2,F11.1,F8.1,F9.0,F14.0) 329
ROTATE AND TRANSLATE AXES FOR PLOT OF DAILY POSITIONS
DO 75 I=1,NK 330
TEMP = .97780241408*X(I) - .20952908873*Y(I) + 3.0032502718 331
Y(I) = .20952908873*X(I) + .97780241408*Y(I) - 4.4699538929 332
75 X(I) = TEMP 333

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C PUNCH 11 CARDS USEABLE FOR A LATER PLOT OF TRACK 334  
 WRITE(52,76) LG,LF,NK 335  
 76 FORMAT (2A8,I2,6I1H ) 335  
 WRITE(52,78) (((RX(I,J),I=1,10),LG,LF,J),J=1,2), 336  
 + (((RY(I,J),I=1,10),LF,LG,J),J=1,2) 337  
 78 FORMAT (10F5.2,2A8,I2,11I1H ) 338  
 CALL DRAW (NK,X,Y,3,4,LF,IT,2.,2.,0,0,0,2,2,9,15,0, LAST) 339  
 WRITE(51,93) 340  
 93 FORMAT (1H1) 341  
 C PROCEED TO COMPUTE THE ROUTE OF NEXT SHIP 342  
 80 CONTINUE 342  
 STOP 343  
 END 344  
 SUBROUTINE TERP 345  
 DIMENSION MHD(4608),YC(8),HT(4,4),CT(4,4),ST(4,4),YVARS(8),P(4), 346  
 + Q(4),PX(4),QY(4),HD(4),CD(4),SD(4),HS(4),CS(4),SS(4),HP(4),CP(4), 347  
 + SP(4),HPX(4),HPY(4),CPX(4),CPY(4),SPX(4),SPY(4),C(4),XHD(4608) 348  
 COMMON MHD,TC,YC,H,HX,HY,CK,CKX,CKY,SK,SKX,SKY,XK,YVARS,XLG,XLT, 349  
 + A,B,CC,DA,DB,DC,LR 350  
 EQUIVALENCE (MHD,XHD),(ID,ARG) 35  
 MASK= 77777777B 35  
 DTC = 2.\*TC 35  
 L = XINTF(DTC) 35  
 IF (L-3) 1,1,7 35  
 1 TT = (-INTF(DTC)+DTC)\*2. - 1. 35  
 TP1= TT + 1. 35  
 TM1= TT - 1. 35  
 T2M= TP1\*TM1 35  
 IF (L) 2,2,3 36  
 2 K4 = 3 36  
 TM3= TT - 3. 36  
 C(1)= TM1\*TM3/8. 36  
 C(2)=-TP1\*TM3/4. 36  
 C(3)= T2M/8. 36  
 GO TO 16 36  
 3 K4 = 4 36  
 IF (L-2) 4,4,6 36  
 4 G = (3.\*TT+2.)\*TT - 9. 36  
 F = -4.\*TT + G 37  
 C(1)= -T2M\*TM1/16. 37  
 C(2)= G\*TM1/16. 37  
 5 C(3)= -F\*TP1/16. 37  
 C(4)= T2M\*TP1/16. 37  
 GO TO 15 37  
 6 C(1)= -T2M\*TM1/16. 37  
 C(2)=((2.\*TT+1.)\*TT-7.)\*TM1/12. 37  
 C(3)=((1.-TT)\*TT+4.)\*TP1/8. 38  
 C(4)= T2M\*TP1/48. 39  
 GO TO 15 39  
 7 L = XINTF(TC-2.) + 4 31

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1 IF (L-8) 9,8,8 382
8 K4 = 1 383
  L = 7 384
  C(1) = 1. 385
  GO TO 16 386
9 TT = (-INTF(TC)+TC)*2. - 1. 387
  TP1 = TT + 1. 388
  TM1 = TT - 1. 389
  T2M = TP1*TM1 390
    G = (3.*TT+2.)*TT - 9. 391
    F = -4.*TT + G 392
  C(1) = -T2M*TM1/16. 393
  IF (L-7) 11,10,8 394
10 K4 = 2 395
  C(2) = (G*TM1 + (T2M-F)*TP1)/16. 396
  GO TO 15 397
11 C(2) = G*TM1/16. 398
  IF (L-6) 13,12,10 399
12 K4 = 3 400
  C(3) = (T2M-F)*TP1/16. 401
  GO TO 15 402
13 K4 = 4 403
  IF (L-5) 14,5,12 404
14 C(1) = -T2M*TM1/6. 405
  C(2) = ((5.*TT+2.)*TT-11.)*TM1/16. 406
  C(3) = ((-5.*TT+4.)*TT+13.)*TP1/24. 407
  C(4) = T2M*TP1/16. 408
15 L = L-1 409
16 M = XINTF(YC(5)) - 2 410
  N = XINTF(YC(6)) - 2 411
  XX = (-INTF(YC(5))+YC(5))*2.0 - 1.0 412
  YY = (-INTF(YC(6))+YC(6))*2.0 - 1.0 413
  XP1 = XX + 1.0 414
  XM1 = XX - 1.0 415
  YP1 = YY + 1.0 416
  YM1 = YY - 1.0 417
  X2M = XP1*XM1 418
  Y2M = YP1*YM1 419
  P(1) = -XM1*X2M/16. 420
  P(2) = ((3.*XX+2.)*XX-9.)*XM1/16. 421
  P(3) = (-XX*XX+9.)/8. - P(2) 422
  P(4) = XP1*X2M/16. 423
  Q(1) = -YM1*Y2M/16. 424
  Q(2) = ((3.*YY+2.)*YY-9.)*YM1/16. 425
  Q(3) = (-YY*YY+9.)/8. - Q(2) 426
  Q(4) = YP1*Y2M/16. 427
  IF (LR) 17,18,17 428
17 PX(4) = (3.*XX-1.)*XP1/8. 429
  PX(1) = XX/2. - PX(4) 430
  PX(2) = (9.*XX-11.)*XP1/8. 431

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PX(3)= -XX/2. - PX(2) 432
QY(4)= (3.*YY-1.)*YP1/8. 433
QY(1)= YY/2. - QY(4) 434
QY(2)= (9.*YY-11.)*YP1/8. 435
QY(3)= -YY/2. - QY(2) 436
18 DO 27 K=1,K4 437
  HP(K) = 0.0 438
  CP(K) = 0.0 439
  SP(K) = 0.0 440
  IF (LR) 19,20,19 441
19 HPX(K)= 0.0 442
  HPY(K)= 0.0 443
  CPX(K)= 0.0 444
  CPY(K)= 0.0 445
  SPX(K)= 0.0 446
  SPY(K)= 0.0 447
20 KK = ((K+L)*32+N)*18 + M - 594 448
  DO 23 J=1,4 449
    HD(J) = 0.0 450
    CD(J) = 0.0 451
    SD(J) = 0.0 452
    IF (LR) 21,22,21 453
21 HS(J) = 0.0 454
  CS(J) = 0.0 455
  SS(J) = 0.0 456
22 JJ = 18*J + KK 457
  DO 23 I=1,4 458
    II = I + JJ 459
    HT(I,J) = XHD(II) 460
    ID = MHD(II) .AND. MASK 461
    ID = ID * 16777216 462
    CT(I,J) = COSF(ARG) 463
23 ST(I,J) = SINF(ARG) 464
  DO 25 I=1,4 465
  DO 25 J=1,4 466
    HD(I) = Q(J)*HT(I,J) + HD(I) 467
    CD(I) = Q(J)*CT(I,J) + CD(I) 468
    SD(I) = Q(J)*ST(I,J) + SD(I) 469
    IF (LR) 24,25,24 470
24 HS(I) = P(J)*HT(J,I) + HS(I) 471
  CS(I) = P(J)*CT(J,I) + CS(I) 472
  SS(I) = P(J)*ST(J,I) + SS(I) 473
25 CONTINUE 474
  DO 27 I=1,4 475
    HP(K) = HD(I)*P(I) + HP(K) 476
    CP(K) = CD(I)*P(I) + CP(K) 477
    SP(K) = SD(I)*P(I) + SP(K) 478
    IF (LR) 26,27,26 479
26 HPX(K)=HD(I)*PX(I) + HPX(K) 480
  CPX(K)=CD(I)*PX(I) + CPX(K) 481

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SPX(K)=SD(I)*PX(I) + SPX(K) 482
HPY(K)=HS(I)*QY(I) + HPY(K) 483
CPY(K)=CS(I)*QY(I) + CPY(K) 484
SPY(K)=SS(I)*QY(I) + SPY(K) 485
27 CONTINUE 486
    H = 0.0 487
    CK = 0.0 488
    SK = 0.0 489
    IF (LR) 28,29,28 490
28   HX = 0.0 491
    HY = 0.0 492
    CKX = 0.0 493
    CKY = 0.0 494
    SKX = 0.0 495
    SKY = 0.0 496
29   DO 31 K=1,K4 497
    H = C(K)*HP(K) + H 498
    CK = C(K)*CP(K) + CK 499
    SK = C(K)*SP(K) + SK 500
    IF (LR) 30,31,30 501
30   HX = C(K)*HPX(K) + HX 502
    HY = C(K)*HPY(K) + HY 503
    CKX = C(K)*CPX(K) + CKX 504
    CKY = C(K)*CPY(K) + CKY 505
    SKX = C(K)*SPX(K) + SKX 506
    SKY = C(K)*SPY(K) + SKY 507
31   CONTINUE 508
    RAD = SQRTF(CK*CK + SK*SK) 509
    CK = CK/RAD 510
    SK = SK/RAD 511
    RETURN 512
    END 513
    SUBROUTINE ANGLE 514
    DIMENSION MHD(4608),YC(8),YVARS(8) 515
    COMMON MHD,TC,YC,H,HX,HY,CK,CKX,CKY,SK,SKX,SKY,XK,YVARS,XLG,XLT,
+    A,B,CC,DA,DB,DC,LR 516
    DELX = YVARS(5) - 24. 517
    DELY = YVARS(6) - 16. 518
    COSXK = -DELX*CK - DELY*SK 519
    SINXK = DELX*SK - DELY*CK 520
    IF (COSXK) 2,1,2 521
1   XK = SIGNF(90.,SINXK) 522
    GO TO 6 523
2   XK = ATANF(SINXK/COSXK)*57.29577951 524
    IF (COSXK) 3,6,6 525
3   IF (SINXK) 5,4,4 526
4   XK = XK + 180. 527
    GO TO 6 528
5   XK = XK - 180. 529
6   IF (XK) 7,8,8 530
                                531

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7 XK = 360. + XK 532
8 XT = DELX*.98480775 - DELY*.17364818 533
  YT = DELX*.17364818 + DELY*.98480775 534
  RAD= SQRTF(XT*XT + YT*YT) 535
  IF (XT) 10,9,10 536
9 XLG = SIGNF(90.0,YT) 537
  GO TO 14 538
10 XLG = ATANF(YT/XT)*57.29577951 539
  IF (XT) 11,14,14 540
11 IF (YT) 13,12,12 541
12 XLG = XLG + 180. 542
  GO TO 14 543
13 XLG = XLG - 180. 544
14 XLT = -ATANF(RAD/31.205)*114.591559 + 90.0 545
  RETURN 546
  END 547
  SUBROUTINE AP3 548
  DIMENSION MHD(4608),YC(8),YVARS(8) 549
  COMMON MHD,TC,YC,H,HX,HY,CK,CKX,CKY,SK,SKX,SKY,XK,YVARS,XLG,XLT,
+     A,B,CC,DA,DB,DC,LR 550
  R1 = SQRTF((.062760850324*H-.60018313990)*H+4.7014047597) 551
  VF = 0.021541997619*H + 19.278272298 - R1 552
  R2 = SQRTF((.060104035000*H-.96636105838)*H+6.1294779871) 553
  B = -0.12663045716*H + 19.585778258 - R2 554
  IF (H-17.) 1,1,2 555
1 R3 =SQRTF((.083601632403*H-1.3340008783)*H+7.1705253492) 556
  VH = -0.24791650490*H + 19.793624009 - R3 557
  GO TO 3 558
2 R4 =SQRTF((.055777533214*H-3.0851911409)*H+45.698170763) 559
  VH = -0.31013284648*H + 14.848653764 + R4 560
3 A = (VF+VH)*.5 561
  CC = A-VH 562
  IF (LR) 4,8,4 563
4 DVF= (-.062760850324*H+.30009156995)/R1 +0.021541997619 564
  DB = (-.060104035000*H+.48318052919)/R2 - 0.12663045716 565
  IF (H-17.) 5,5,6 566
5 DVH=(-.083601632403*H+.66700043915)/R3-0.24791650490 567
  GO TO 7 568
6 DVH= (.055777533214*H-1.54259557045)/R4-0.31013284648 569
7 DA =(DVF+DVH)*.5 570
  DC =DA-DVH 571
8 RETURN 572
  END 573
  END 574
  FINIS 575
  576

```

EXECUTE.

OB 0574 BLEICK BOX 6  
 C2AP3 DECEMBER 6 1966 JUL26,66  
 666JUL26,66J207 00.-122.5 37.9 139.6 35.6 10024 7

1

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SUBROUTINE AP2
DIMENSION MHD(4608),YC(8),YVARS(8)
COMMON MHD,TC,YC,H,HX,HY,CK,CKX,CKY,SK,SKX,SKY,XK,YVARS,XLG,XLT,
+ A,B,CC,DA,DB,DC,LR
R1 = SQRTF((.041783709356*H-.42321401072)*H+2.2342337579)
VF = -.028281950577*H + 17.494735347 - R1
R2 = SQRTF((.058458667266*H-.90729449065)*H+6.4033842487)
B = -0.14520001518*H + 18.530490911 - R2
IF (H-15.) 1,1,2
1 R3 =SQRTF(( .23341292994*H-3.1096617758)*H+29.275404601)
VH = -0.25152614353*H + 21.408836894 - R3
GO TO 3
2 R4 =SQRTF(( .14668786198*H-6.8828319323)*H+105.12448592)
VH = -0.36970234218*H + 11.346369501 + R4
3 A = (VF+VH)*.5
CC = A-VH
IF (LR) 4,8,4
4 DVF= (-.041783709356*H+.21160700536)/R1 - .028281950577
DB = (-.058458667266*H+.45364724533)/R2 - 0.14520001518
IF (H-15.) 5,5,6
5 DVH= (-.23341292994*H+1.5548308879)/R3-0.25152614353
GO TO 7
6 DVH= (.14668786198*H-3.44141596615)/R4-0.36970234218
7 DA =(DVF+DVH)*.5
DC =DA-DVH
8 RETURN
END

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-COOP, BOX 6, BLEICK, I/1/0/2/S/56/57, 3, 10000, 0, TAPE - 6 DEC 66.  
-FTN,L,A,E.

```

PROGRAM TAPE
DIMENSION X(900),Y(900),MD(63,63),ND(3969),MHD(18,32,8)
EQUIVALENCE (MD,ND),(ID,ARG),(TEMP,ITEM),(IH,H)
REWIND 1
REWIND 2
ISCALE = 2000000000000000B
MASK = 7777777700000000B
0
1
2
3
4
5
6
C READ COORDINATES FOR MAP GRID OF DRAW SUBROUTINE
READ(50,1) (X(I),I=1,390), (Y(I),I=1,390)
7
8
1 FORMAT (15F5.3)
9
10
2 WRITE(2) X,Y
11
12
3 FORMAT (37HO  PARITY ERROR OCCURRED ON X,Y WRITE/)
13
4 DO 43 K=1,8
C READ WAVE DIRECTION FROM FLEET NUMERICAL WEATHER FACILITY TAPE
5 BUFFER IN(1,2) (ND(1),ND(3969))
14
6 IF(UNIT,1) 6,14,8,10
15
7 GO TO 5
16
8 WRITE(51,9) K
17

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9 FORMAT (44HO DIRECTION EOF OR EOT ERROR OCCURRED ON K=I1/) 18
  STOP
10 WRITE(51,11) K
11 FORMAT (49HO DIRECTION PARITY OR LENGTH ERROR OCCURRED ON K=I1/) 21
  M = LENGTHF(1)
  IF (M-3969) 12,14,12
12 WRITE(51,13) M
13 FORMAT (28HO DIRECTION BUFFER LENGTH =I5/) 25
C COMPUTE WAVE DIRECTION K FROM X AXIS OF STEREOGRAPHIC GRID
14 DO 42 I=1,18
  DELX = I-24
  DO 42 J=1,32
  DELY = J-16
    ID = MD(I+8,J+16)/2048 + ISCALE
    ARG = (ARG + 0.0)*11.17010721
    COS = COSF(ARG)
    SIN = SINF(ARG)
    ABS = -DELX*COS - DELY*SIN
    ORD = DELX*SIN - DELY*COS
    IF (ABS) 36,35,36
35 TEMP = SIGNF(1.5707963268,ORD)
  GO TO 40
36 TEMP = ATANF(ORD/ABS)
  IF (ABS) 37,40,40
37 IF (ORD) 39,38,38
38 TEMP = TEMP + 3.1415926536
  GO TO 40
39 TEMP = TEMP - 3.1415926536
40 IF (TEMP) 41,42,42
41 TEMP = TEMP + 6.2831853072
C SHIFT FLOATING-POINT K TO LOWER HALF OF MHD MATRIX WORD
42 MHD(I,J,K) = ITEM/16777216
C READ WAVE PERIOD FROM FLEET NUMERICAL WEATHER FACILITY TAPE (NOT USED)
  BUFFER IN(1,2) (ND(1),ND(3969)) 48
15 IF(UNIT,1) 16,24,18,20
16 GO TO 15
18 WRITE(51,19) K
19 FORMAT (41HO PERIOD EOF OR EOT ERROR OCCURRED ON K=I1/) 52
  STOP
20 WRITE(51,21) K
21 FORMAT (46HO PERIOD PARITY OR LENGTH ERROR OCCURRED ON K=I1/) 55
  M = LENGTHF(1)
  IF (M-3969) 22,24,22
22 WRITE(51,23) M
23 FORMAT (25HO PERIOD BUFFER LENGTH =I5/) 59
C READ WAVE HEIGHT H FROM FLEET NUMERICAL WEATHER FACILITY TAPE
24 BUFFER IN(1,2) (ND(1),ND(3969)) 60
25 IF(UNIT,1) 26,34,28,30
26 GO TO 25
28 WRITE(51,29) K

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29 FORMAT (41H0 HEIGHT EOF OR EOT ERROR OCCURRED ON K=I1/) 64
  STOP 65
30 WRITE(51,31) K 66
31 FORMAT (46H0 HEIGHT PARITY OR LENGTH ERROR OCCURRED ON K=I1/) 67
  M = LENGTHF(1) 68
  IF (M-3969) 32,34,32 69
32 WRITE(51,33) M 70
33 FORMAT (25H0 HEIGHT BUFFER LENGTH = I5/) 71
PACK FLOATING-POINT H AND K IN MHD MATRIX
34 DO 43 I=1,18 72
  DO 43 J=1,32 73
    IH = MD(I+8,J+16)/2048 + ISCALE 74
    H = (H + 0.0)*64. 75
    IH = IH .AND. MASK 76
43 MHD(I,J,K) = MHD(I,J,K) + IH 77
  REWIND 1 78
  WRITE(2) MHD 79
  IF (IOCHECK,2) 44,46 80
44 WRITE(51,45) 81
45 FORMAT (37H0 PARITY ERROR OCCURRED ON MHD WRITE/) 82
46 END FILE 2 83
  REWIND 2 84
PRINT PART OF MHD MATRIX TO CHECK PACKING OF DATA
  WRITE(51,47) (((MHD(I,J,K),I=1,7),J=1,32,31),K=1,8) 85
47 FORMAT (7017/) 86
  STOP 87
  END 88
  END 89
    FINIS 90
:EXECUTE.
978 9781746117461 978 978 2070 4931 4133 3388 2698 2065 1491 978 978ABS 1
491 2064 2697 5198 4550 3956 3418 2937 2515 2152 1851 1612 1435 1321 1271ABS 2
284 1361 1501 1704 1969 2296 2684 3130 3635 4197 4814 5484 6205 6976 7794ABS 3
764 9841 8966 8144 7378 6669 6021 5437 4917 4465 4082 3769 3528 3359 3262ABS 4
240 3290 3414 3611 3879 4219 4628 5106 5651 6259 6931 766110146 9307 8535ABS 5
834 7207 6658 6188 5800 5496 5278 5146 5102 5145 5275 5491 5793 6179 6647ABS 6
196 7821 8520 92911012811028119871300014062174611746116477155231460013714ABS 7
868120671131210608 9957 9363 8827 8353 7942 7596 7316 7104 6960 6885 6880ABS 8
944 7078 7280 7550 7886 8288 8753 9279 9865105071120411951127461567214829ABS 9
025132651255111887112771072310227 9793 9422 9116 8877 8705 8601 8567 8601ABS10
705 8877 9116 9422 979310227107231127711887125511326514026148291567316551ABS11
4611746116663158971516714475138251322012664121591170811311109731069410475ABS12
3181022410193102241031810475106941097311311117081215912664132201382514475ABS13
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361214911979118581178511760117851185811979121491236612628129361328813682ABS15
171459015100156451622116827174611746116989165391611315712153881499114674ABS16
3871413113908137171356013438133501329713279132971335013438135601371713908ABS17
311438714674149911533815712161131653916989174611746117150168551657716317ABS18
1741585115647154621529915156150351493514857148011476814757147681480114857ABS19
351503515156152991546215647158511607416317165771685517150174611746117312ABS20

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171721704116919168061670216608165231644816382163271628116246162201620516200ABS1  
162051622016246162811632716382164481652316608167021680616919170411717217312ABS2  
17461174611672215277174611746113665118241746117461 9667 70621746117461 3797ABS3  
 978 9781746117461 978 9781746117461 978 9781746117461 978 97817461ABS4  
17461 978 9781746117461 978 9781746117461 978 9781746117461 2520 5878ABS5  
1746117461 86421099117461174611304014870174611746116537 ABS5  
 6292870528705 629 629 2224 629 629 1612 2637 3700 4797 5927 7085253220ORD1  
264802760928705287052772126703256552457823478223572121720063188981772516547ORD2  
1536814192130221186110713 9580 8467 7377 6312 5275 4271 3302 2369 1478 629ORD3  
 629 1408 2242 3127 4061 5039 6059 7116 8207 932810473116401282414020152240RD4  
164321763918841200332121122371235072461725695267392774328705287052777226783ORD5  
2574224655235282236421171199531871817470162161496213714124781126110067 8903ORD5  
 7774 6686 5645 4654 3720 2846 2037 1297 629 629 976 1379 1844 2372 2958ORD7  
 3601 4298 5046 5842 6682 7562 8480 943110410114151244013481145331559316656ORD8  
177161877019813208412184922832237882471025597264432724628001287052870528163ORD9  
275642691126207254562466023825229532205021118201641919018203172051620315202ORD0  
1420413217122431128810357 9453 8582 7746 6951 6200 5496 4843 4244 3702 3219ORD1  
 2797 4582 5005 5483 6013 6593 7220 7890 8602 93501013210943117801263813514ORD2  
144031530116204171061800418893197692062721464222762305723806245172518725814ORD3  
263942692427402278252605225660252272475624248237052313022525218932123720559ORD4  
1986219149184241768916948162041545914718139831325812545118491117010514 9882ORD5  
 9277 8702 8159 7651 7180 6747 6355 8154 8507 8807 9294 9726101811065711154ORD6  
116681219912744133011386914445150281561516204167921737917962185381910619663ORD7  
202082073921254217502222622681231132352023900242532236022060217432141221067ORD8  
207092033819957195661916618757183421792117496170671663616204157711534014911ORD9  
144861406513650132421284112450120691169811340109951066410347100471222212442ORD0  
126671289713133133721361613864141151437014627148861514715410156741593816204ORD1  
164691673316997172601752117781180381829218543187911903519275195101974019966ORD2  
201852726128705287052522423685287052870522466214622870528705206081986428705ORD3  
287052792919200185942555823357180311750021277192781698916491173271539415997ORD4  
1549913448114591499114464 9395 72161390713309 4876 23181265511926 629 629ORD5  
1109310117 629 629 8938 7461 629 629 5521 2814 629 ORD6

List of cards in programs TAPE, VC2AP3 and AP2 requiring changes if the geometric dimensions and/or origin of the MHD array are changed:

TAPE: 1, 26, 27, 28, 29, 30, 72, 73, 74 and perhaps 85, and the 52 input BCD data cards for the computer plotting of the map grid.

VC2AP3: 1, 86, 87, 88, 89, 105, 106, 109, 110, 141, 142, 157, 158, 163, 164, 202, 203, 223, 224, 296, 297, 303, 304, 331, 332, 346, 348, 448, 457, 515, 518, 519 and 549.

## AP2: DIMENSION statement.

A. IDENTIFICATION:

TITLE: General Graph Output Subroutine  
CO-OP ID: J7-NPS-DRAW (FORTRAN 60)  
CATEGORY: Output for Off-Line Plotting  
PROGRAMMER: J. R. Ward  
DATE: February 1964;  
REVISED: June 1965

B. PURPOSE:

This subroutine, when provided with the necessary information, generates a magnetic tape in the proper format for subsequent off-line graph plotting using the CDC 160 or 160A GRAFPLOT program and a CalComp 165 Plotter (see references 1 and 2). Provision is made for curve drawing and point plotting, automatic scaling, graph titling and axis annotating. An attempt was made to provide a considerable amount of flexibility, at the expense, necessarily, of a relatively large number of arguments and a rather high memory requirement.

C. USAGE:

1. Definitions:

In what follows the word "graph" will be taken to mean one piece or frame of graph paper on which there may be plotted one or more curves and/or sets of points. A "curve" will mean a continuous line generated by the sequence of straight lines joining successive points of the set defining the curve. A "point plot" will describe the representation of a succession of points by means of symbols (such as a cross) on the graph. The points are not connected in a point plot.

2. Calling Arguments:

All necessary information is transferred to DRAW through the calling arguments. The call statement is: CALL DRAW (NUMPTS, X, Y, MODCURV, ITYPE, LABEL, ITITLE, EXSCALE, YSCALE, IXUP, IYRIGHT, MODEXAX, MODEYAX, IWIDE, IHIGH, IGRID, LAST)

It is important to realize that one and only one curve or set of points is plotted each time DRAW is called. However, it is possible to call DRAW repeatedly if several curves and/or sets of points are wanted on one graph.

The calling arguments are as follows:

- a. NUMPTS: The number of points defining a curve ( $2 \leq \text{NUMPTS} \leq 900$ ), or the number of points to be point plotted ( $2 \leq \text{NUMPTS} \leq 30$ ).
- b. X: The array of X-ordinates ( $|X_i| \leq 10^{99}$  for  $i=1,2,\dots, \text{NUMPTS}$ ). X must be dimensioned at least equal to NUMPTS in the calling program.  
All points will be considered to have the same X-ordinate if  $|X_{\text{max}} - X_{\text{min}}| \leq 10^{-97}$ . The common value will be put equal to zero if  $|X_{\text{max}}| \leq 10^{-97}$ .
- c. Y: The array of Y-ordinates, with properties corresponding to the X-ordinates, above. Y must be dimensioned at least equal to NUMPTS in the calling program.
- d. MODCURV: Controls the number of curves, and/or sets of points on one graph:  
- 0 This is the only curve, or set of points, to be plotted on this graph.  
- 1 This is the first of two or more curves, and/or sets of points, to be plotted on this graph.  
- 2 This is an intermediate curve, or set of points.  
- 3 This is the last curve, or set of points, for this graph.
- e. ITYPE: Controls the type of plot (i.e., curve or point plot):  
- 0 This set of points is to be represented by a curve.  
- 1 These points are to be plotted with a cross (x).  
- 2 These points are to be plotted with a plus (+).  
- 3 These points are to be plotted with a square (□).  
- 4 These points are to be plotted with a diamond (◊).  
- 5 These points are to be plotted with a triangle (Δ).

f. LABEL: This is a Hollerith curve or point identifier. If a curve is being drawn, LABEL must have 4 characters (including any blanks), and these will be reproduced beside the end of the curve. This argument can be set in the calling program by a statement such as

LABEL = 4H<sub>1</sub>ONE ( <sub>1</sub> = blank)

or     LABEL = 4H1234

or      **LABEL = 4H~~~~~**      The latter must be used when no label is wanted.

If a set of points is being plotted, LABEL is an 8-character identifier. The first 4 characters will be reproduced beside the first point, and the last four characters will be reproduced alongside the last point. This argument can be set by statements such as

LABEL = 8HFRSTLAST

or . LABEL = 8H<sup>111111</sup> ONE

or     LABEL = 8H<sub>1</sub>ONE<sub>2</sub>123

or      LABEL = 8H<sub>11111111</sub>

It is better to want less.

The above arguments, a. through f. (and q.), have

meaning every time DRAW is called. On the other hand,

the remaining arguments, g. through p., have no meaning

except when MODCURV = 0 or 1.

g. ITITLE: An array of twelve 8-character Hollerith words, the first six of which will form the first title line, and the last six the second. The array must be dimensioned 12 in the calling program, must contain the user's job identification, and must have unwanted characters set to blank. For example:

```
DO 1 I = 1,12
1 ITITLE(I) = 8H
      ITITLE(1) = 8HASMITH,A
      ITITLE(2) = 8HJ.AJ.AA
      ITITLE(7) = 8HATESTIT.
```

h. EXSCALE: X-scale in units per inch ( $10^{-99} \leq \text{EXSCALE} \leq 10^{99}$ ). EXSCALE will always be rounded off to one figure significance. If EXSCALE = 0, the X-scale will be computed by DRAW. This is called auto-scale.

i. YSCALE: Y-scale in units per inch, with properties corresponding to those of EXSCALE.

j. IXUP: Distance, in inches, of the X-axis from the bottom of the graph ( $0 \leq \text{IXUP} \leq \text{IHIGH}$ ). This argument will be ignored unless MODEXAX = 2, see below.

k. IYRIGHT: Distance, in inches, of the Y-axis from the left of the graph ( $0 \leq \text{IYRIGHT} \leq \text{IWIDE}$ ). This will be ignored unless MODEYAX = 2, see below.

l. MODEXAX: Determines the mode of the X-axis location:

- 0 The X-axis will be located automatically by DRAW, with the origin of Y on the graph.

- 1 The X-axis will be automatically located by DRAW, with the origin of Y moved (in one's imagination) an integer number of inches above or below the graph, if this is appropriate. This option can be used only if the Y-scaling is automatic (YSCALE = 0).
  - 2 The X-axis location will be as specified by IXUP.
- m. MODEYAX: Determines the mode of Y-axis location in the same way as MODEXAX, above, governs the X-axis location.
- n. IWIDE: Width of graph in inches ( $1 \leq IWIDE \leq 9$ ). If IWIDE is out of this range, a value of 8 will be assumed.
- o. IHIGH: Height of graph in inches ( $1 \leq IHIGH \leq 15$ ). If IHIGH is out of range, a value of 8 will be assumed.
- p. IGRID: If IGRID = 1, a 1" x 1" grid will be superimposed on the graph. This is useful only if plain paper is used on the CalComp Plotter.
- q. LAST: Indicates to the calling program whether the previous plot was completed successfully. The codes are:
- 0 Last plot was completed successfully
  - 1 Last plot was not completed successfully.
  - 2 Last plot was not completed successfully, and no further graph output will be attempted until DRAW is next entered with MODCURV = 1 or 0.
  - 3 An attempt was made to enter DRAW with MODCURV  $\neq$  1 or 0 while the error lockout was set.
- This argument must always be a variable name and never a number in the call statement.

### 3. Notes and Comments:

- a. The graph scales and, if MODEXAX = 1 and/or MODEYAX = 1, the amounts of origin offset are always output as part of the graph title.
- b. Each time a graph is completed, a message to this effect is printed on both the standard output and the console typewriter.
- c. There are internal checks of the input to DRAW to prevent incorrect use. If an input error is detected, an attempt will be made, where possible, to complete the plot. If an argument is "corrected" in this process, the user will be so informed on the standard output. If it is not possible to complete the plot, the user will be informed of the reason by a message on the standard output.
- d. If part or all of a curve would fall more than 0.6" laterally beyond the ends of the X-axis, or 0.7" vertically beyond the ends of the Y-axis, the X and/or Y ordinates will be limited so that the curve will typically become a line along part or all of the boundary of the graph as here defined.
- e. If one or more points of a point plot would fall outside the graph area, the plot of that point, or points will be inhibited. The number of such points will be reported to the user on the standard output.
- f. It should be pointed out that the X and Y scaling and axis locating processes are entirely independent, so that, for example, X might be auto-scaled, while the Y-scale is specified. At the same time the X-axis might be located automatically, while the Y-axis location is specified.
- g. It must be remembered that the scales and axis locations of a multi-plot graph are set when DRAW is called for the first time (with MODCURV = 1). Thus the user must attempt, at that time, to achieve scaling and axis location which will be appropriate to all the plots he intends to make on the one graph. Particularly if the automatic features of DRAW are selected, foresight will be demanded of the user in this respect.

### 4. Auto-Scale Properties:

The scale factor is chosen from amongst the values 1, 2 or 5 units per inch, or some power of 10 times one of those values. A curve, or set of points which is plotted with auto-scale will normally lie entirely within the graph area as defined in 3.d., above. The only exception may occur if an axis is placed, by the user, along one edge of the graph (e.g., IXUP = 0, MODEXAX = 2). In such a case, points "outside" the axis are not considered in the selection of a scale factor (e.g., negative  $X_1$  do not affect the choice of scale when IXUP = 0). If automatic axis location as well as auto-scale is selected, the plot, if it does not fill the graph area, will be placed as far as possible towards the bottom-left of the graph area consistent with the fact that the axes can be set in increments of 1" only.

5. Space Required: 3960 cells (excluding the input arrays).
6. Temporary Storage: None
7. Error Print-Outs: There are a large number of possible error print-outs. These are all self-explanatory.
8. Error Returns: All error returns are preceded by self-explanatory error printouts. An error indication is transferred back to the calling program through the argument LAST.
9. Error Stops: None.
10. Tape Mountings: Logical Tape #8 will receive the binary graph output. The standard monitor output will receive the messages to the user.
11. Output Format: The format of the binary graph output records on magnetic tape is described in reference 1. The only difference is that in this program the interpolation option is by-passed (set to zero in the graph output record). See reference 2.
12. Selective Jump and Stop settings: None.
13. Timing: Variable, depending upon the number of points and the options chosen. Typically less than one second per curve or point plot.
14. Accuracy: The accuracy of results is equal to the resolution of the CalComp Plotter, that is, 0.01" in both the X and Y directions.
15. Equipment configuration: CDC 1604 with FORTRAN 60 compiler and Library. A CDC 160 or 160A with CalComp 165 Plotter is needed for the off-line plotting using the appropriate GRAFPLOT program.

**D. REFERENCES:**

1. Weir, Maurice D., Spritzer, Milton and McIlhenny, D. W., "160-A Graph Plot Program," Ident \*B001, SWAP Library, 15 August 1962.
2. Hogg, R. L. and Glover, D. C., "160 Grafplot Routine," Writeup available from Computer Facility, U. S. Naval Postgraduate School, 1 April 1963.
3. U. S. Naval Postgraduate School, Thesis, "Control System Programming, Remote Computing and Data Display," by Robert Lee Hogg and Dennis C. Glover, 1963.

N.B. References 1 and 2 are included in Reference 3 as Enclosures 2 and 1, respectively.

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## 13. ABSTRACT

This report presents an operational computer program for the minimal-time routing of single ships. Although written specifically for VC2AP3 and VC2AP2 vessels operating in a described area of the north Pacific ocean, the program can be modified easily to provide routes for other type vessels in any ocean area of the northern hemisphere. The method of incorporating weather forecasts into the preparation of minimal-time ship routes is described, and possible future developments are discussed.

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KEY WORDS

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